

SOME ASPECTS OF THE RADAR STRUCTURE OF HURRICANE BEULAH ON SEPTEMBER 9, 1967

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ABSTRACT

Hurricane Beulah developed near the island of Martinique on Sept. 7, 1967. About 36 hr after development, the hurricane came within range of the San Juan radar and was then followed by radar for about 34 hr as it moved westward to the south of Puerto Rico.

The variations in the radar configurations of Beulah during that period revealed an interesting feature concerning the evolution of the eye. Initially, the eye consisted of a very small closed ring somewhat isolated from the rest of the precipitation bands. In time, a second eye ring developed just outside the initial one; the hurricane then showed a "double eye" similar to what has been observed occasionally in other hurricanes. Later the inner eye ring dissipated, thus completing a cycle of evolution that, to our knowledge, had not been observed before.

Photographs of the radarscope depicting the changes are presented and discussed, and the development is compared to previously reported double eyes.

1. INTRODUCTION

Hurricane Beulah developing in the Caribbean near the island of Martinique on Sept. 7, 1967, moved northwest, gradually deepening, and passed within 50 mi of Puerto Rico early on September 10 (fig. 1). A few hours later, it took a turn to the west and passed a short distance south of Hispaniola, weakening as it brushed the landmass to the north.

The hurricane was under surveillance by land-based radar in Puerto Rico for about 34 hr from 0500 GMT on September 9 to 1500 GMT on September 10. Radar presentation was excellent, and there was no difficulty in locating the center. Polaroid photographs¹ of the PPI scope were made at about 1-hr intervals.

During most of the 34-hr period of radar surveillance, Beulah intensified while maintaining a fairly steady northwest course. A study of the photographs of the PPI scope made during this period revealed an interesting development in the inner structure of the eye system as seen by radar, featuring a double-eye formation and dissipation. The purpose of this report is to describe this development and discuss it in comparison to somewhat similar cases reported in other hurricanes.

A total of 25 Polaroid photographs were made in the 24-hr period from 0530 GMT on September 9 to 0530 GMT on September 10. Only eight of them, considered most representative, are illustrated in this article.

2. GENERAL DESCRIPTION OF THE RADAR DATA

As hurricane Beulah came within range of the San Juan radar at 0500 GMT on September 9, the eye as seen on radar was open to the southeast with a solid wall cloud about 7 n.mi. thick in the northwest semicircle. The distance of

the hurricane center (200 n.mi.) and attenuation may have prevented observation of the complete wall cloud. The eye had a diameter of approximately 14 n.mi. with the wall cloud isolated from the rest of the precipitation bands by a "clear zone" about 13 n.mi. wide. Farther out in the semicircle north of the center, there was a large nearly solid mass of echoes, a feature frequently observed in tropical cyclones and which has been referred to as the rain shield (Senn and Hiser 1959). The average radius of the outer edge of the rain shield was about 88 n.mi. This same structure was maintained during the next 5 hr.

Beginning at 1030 GMT (fig. 2), the wall cloud as seen on the radarscope began to close toward a full circle. The inner diameter of the eye at 1030 GMT (fig. 2) was about 10 n.mi., smaller than when first observed at 0500 GMT. The width of the clear zone between the outer edge of the wall cloud and the rest of the rainbands had increased, and the rain shield expanded slightly. The central pressure at 0600 GMT was measured by reconnaissance aircraft as 976 mb; it was lower at the time of figure 2. One interesting feature in the configuration of the radar bands is the isolation of the eye ring from the rest of the precipitation system. By 1230 GMT, photographs of the scope showed an eye diameter of 8 n.mi. with the rain shield extending about 100 n.mi. to the north.

A U.S. Navy hurricane reconnaissance aircraft penetrated the hurricane core at 1200 GMT and reported a solid circular wall cloud 9 n.mi. in diameter with feeder bands in all quadrants, presenting a classical hurricane picture on radar. The maximum reported surface wind, about 75 kt, was located near the outer edge of the wall cloud.

At 1430 GMT on September 9 (fig. 3), the photograph of the scope shows the beginning of the development of two concentric wall clouds. The eye diameter at 1430 GMT had decreased to 6 n.mi. and was still isolated from the outer

¹ Mention of commercial products does not constitute an endorsement.

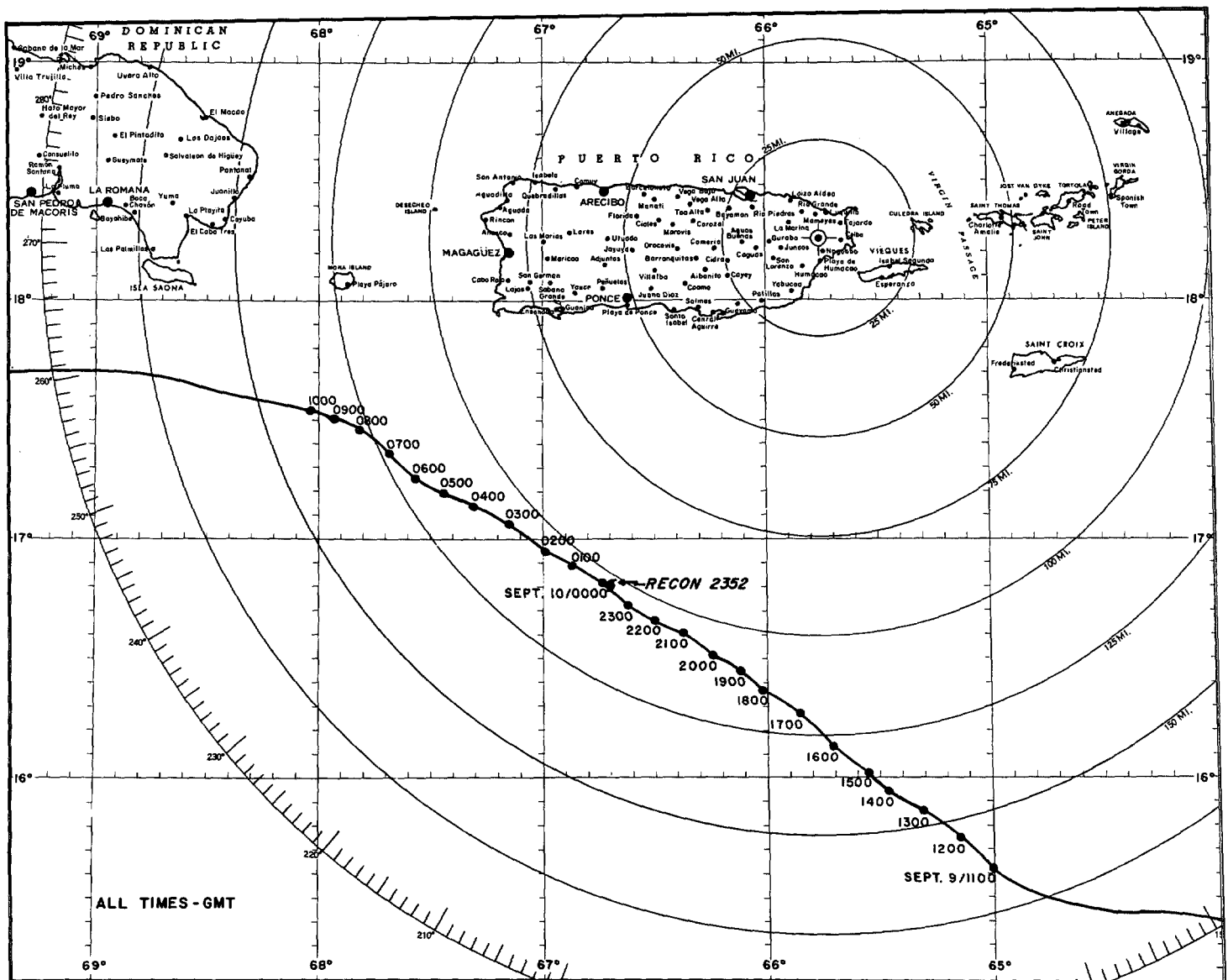


FIGURE 1.—Track of hurricane Beulah south of Puerto Rico showing hourly San Juan radar fixes at 1100 GMT on September 9 to 1000 GMT on Sept. 10, 1967.

rainbands. However, figure 3 shows a thin precipitation band just outside the eye, nearly circular, about 37 n.mi. in diameter, but better defined northeast and southwest of the center. Two hours later at 1630 GMT (fig. 4), this outer band had thickened and formed a near circle around the eye. The configuration of this band resembled the classical figure "9" that has been observed frequently in other hurricanes.

By 1930 GMT (fig. 5), the second band had become better defined and organized in a nearly closed circle around the small eye; the structure resembled then a so-called double eye, reported previously in other past hurricanes (Jordan and Schatzle 1962). The inner diameter of the outer wall cloud or outer eye was about 30 n.mi., while the inner eye was about 6 n.mi. in diameter. At 1800 GMT, a reconnaissance aircraft penetrated the center and reported a

circular eye, well defined in all quadrants with a central pressure of 950 mb and maximum winds of 100 kt located at a radius of about 10 n.mi. They reported an eye diameter of 10 n.mi., which does not completely agree with the measurements obtained from figure 5. It is interesting to note that according to these reports the radius of maximum winds at 1800 GMT was located in the clear zone between the two concentric wall clouds.

Subsequent photographs of the scope indicate that the outer wall cloud became completely closed between 2030 and 2100 GMT. By 2030 GMT, the radius of the rain shield had shrunk to about 60 n.mi. and remained about this size for the following 6 hr.

The photograph of the scope at 2130 GMT (fig. 6) shows both concentric wall clouds completely closed—the typical double-eye configuration. The inner eye has a

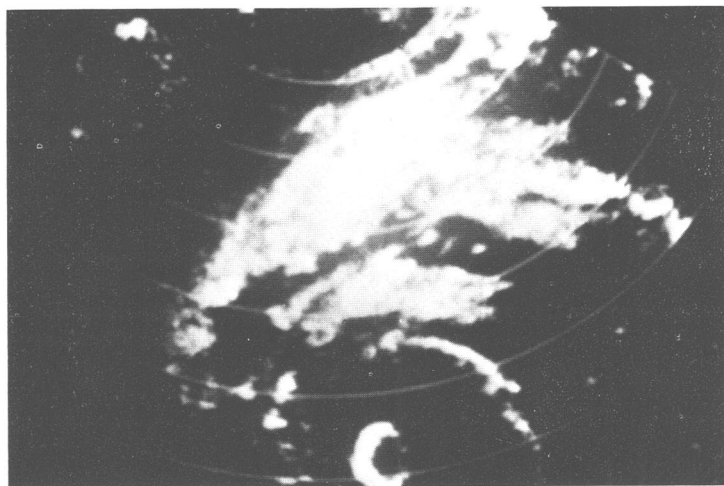


FIGURE 2.—Photograph of the San Juan PPI scope taken at 1030 GMT on Sept. 9, 1967. Range markers are at 20-n.mi. intervals; the top of the photograph is north.

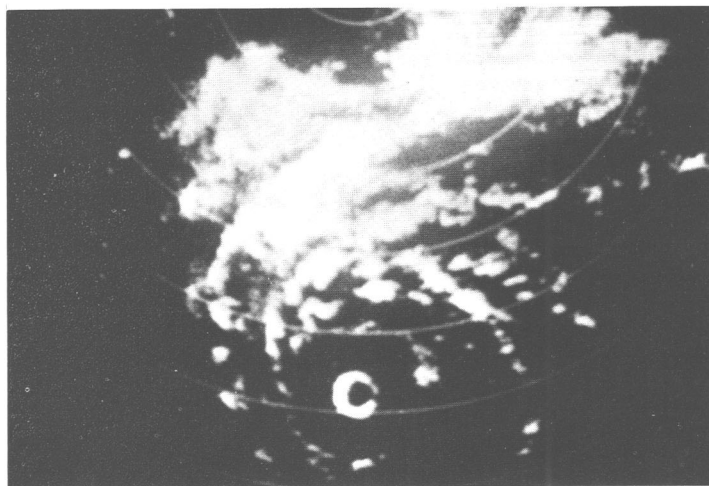


FIGURE 4.—Similar to figure 2, taken at 1630 GMT on Sept. 9, 1967.

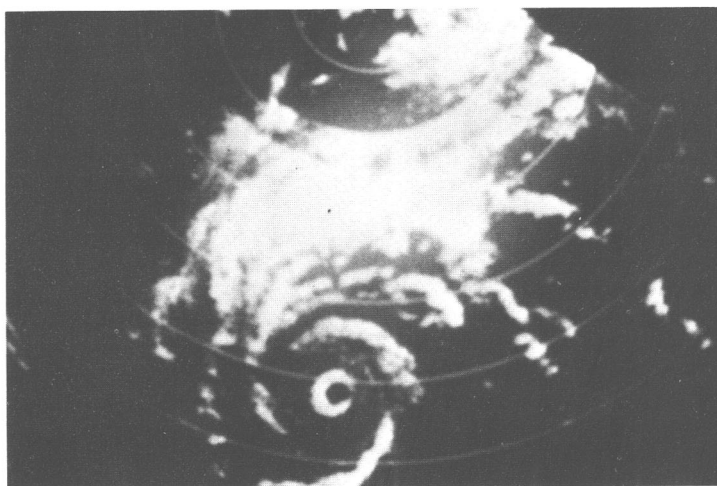


FIGURE 3.—Similar to figure 2, taken at 1430 GMT on Sept. 9, 1967.

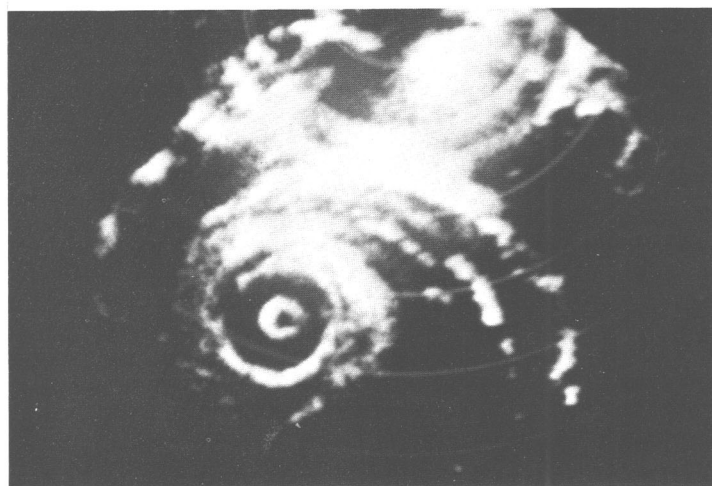


FIGURE 5.—Similar to figure 2, taken at 1930 GMT on Sept. 9, 1967.

diameter of 3 n.mi. by 5 n.mi., with the axis apparently oriented north-northeast/south-southwest. The wall cloud averages 4 n.mi. in thickness. The outer eye has a diameter of about 24 n.mi., and the thickness of the wall cloud varied from 5 to 13 n.mi.

An Air Force reconnaissance aircraft penetrated the hurricane eye at 2352 GMT on September 9 and reported the double-eye formation. The inner eye was described as oval, 6 n.mi. wide by 8 n.mi. long, oriented 020° to 200° . The outer eye was circular with a 25-n.mi. diameter. Central pressure was 940 mb, the lowest pressure reported while hurricane Beulah was in the eastern Caribbean. The maximum wind reported by the aircraft was 105 kt at the flight level of 8,500 ft and was reported to be located at a radius of 12 n.mi. This would position it near the

inner edge of the outer wall cloud. No surface wind was reported.

The photograph taken at 2230 GMT showed the continued perfect double-eye configuration, with a very small oval inner eye and an outer eye diameter of 22 n.mi., which was less than observed earlier. No photograph was taken at 2330 GMT because of temporary radar failure, but the photograph taken at 0045 GMT on September 10 (fig. 7) showed deterioration of the radar structure of the inner eye. The inner eye at 0045 GMT appeared open to the east, while the outer eye diameter had decreased to 18 n.mi. By 0230 GMT on September 10 (fig. 8), only a couple of radar echo segments are visible as remains of the inner wall cloud. These segments are located near the inner edge of the outer wall cloud. The diameter of the "new single eye" (fig. 8) is 16 to 18 n.mi.

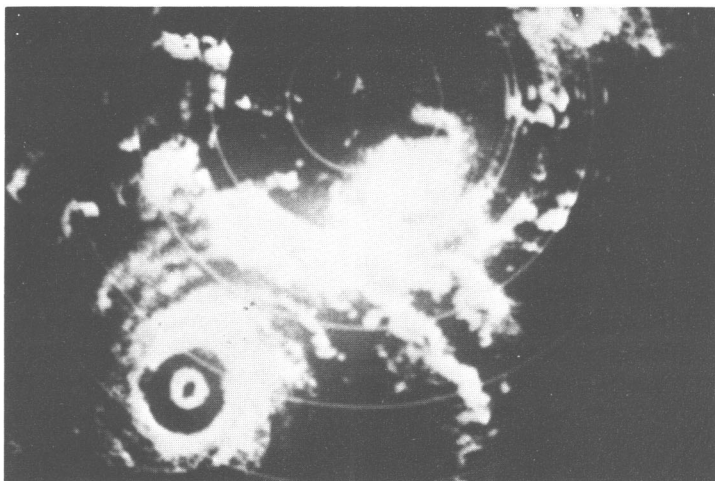


FIGURE 6.—Similar to figure 2, taken at 2130 GMT on Sept. 9, 1967.

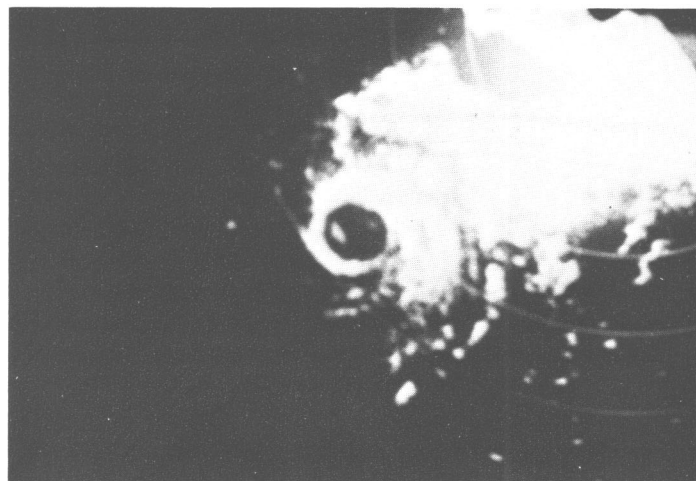


FIGURE 8.—Similar to figure 2, taken at 0230 GMT on Sept. 10, 1967.

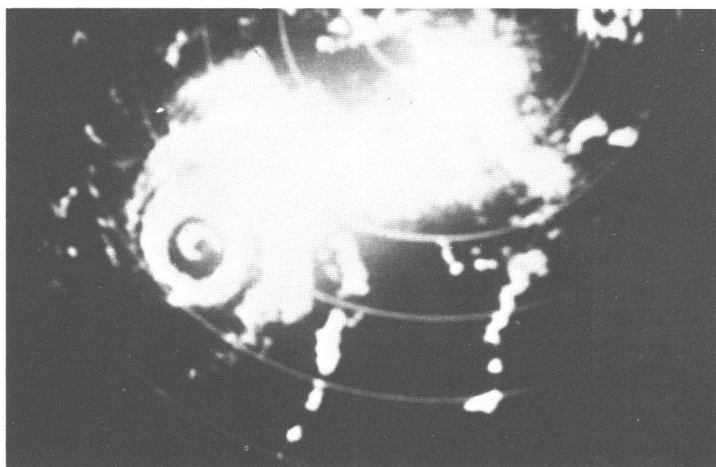


FIGURE 7.—Similar to figure 2, taken at 0045 GMT on Sept. 10, 1967.

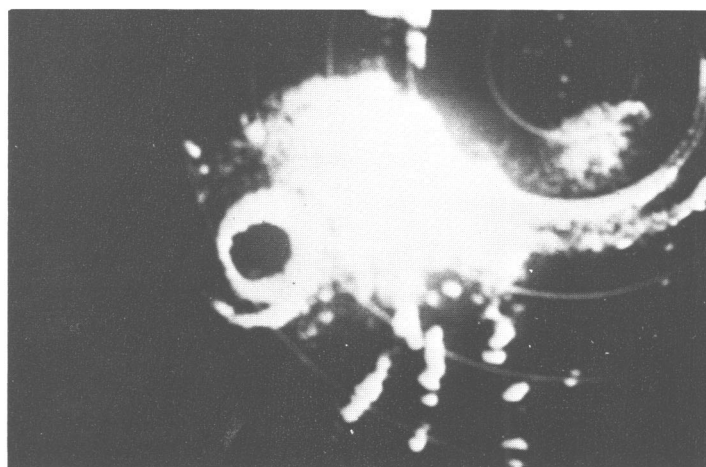


FIGURE 9.—Similar to figure 2, taken at 0330 GMT on Sept. 10, 1967.

The final photograph at 0330 GMT on September 10 (fig. 9) shows Beulah's eye at the end of the double-eye cycle of evolution. Shortly after this time, the hurricane eye appeared open to the west, probably because of attenuation due to increasing range from the antenna. At 0650 GMT on September 10, an Air Force reconnaissance aircraft located hurricane Beulah by radar and reported that the eye was circular with no double-eye bands observed.

3. DISCUSSION AND CONCLUSION

The development of two concentric eye wall clouds appears to be a rather infrequent occurrence. A few cases have been cited. The complete cycle of evolution illustrated here had not been observed and documented. In this instance, the formation of the outer eye wall was accompanied by a shrinking in the diameter of the original

eye. This decrease occurred in both the inner and outer diameters of the original wall cloud. Similarly, as the outer second wall cloud formed, it too experienced a decrease in diameter until the original inner wall cloud began to dissipate. The extent of the rain shield may also be involved in the cycle. The radius of the rain shield increased slightly until the new outer eye began to form. The rain shield decreased by some 40 percent as the double eye evolved and then expanded again after the inner eye dissipated. The size of the rain shield may have been influenced by the proximity of the island of Puerto Rico, but it seems unlikely that this could account for all of the variation.

It is especially interesting that the double eye appeared shortly before Beulah reached maximum intensity with the central pressure dropping to 940 mb. This is probably more than a coincidence as there are other cases of double eyes occurring just prior to the time of greatest intensity.

A double-eye structure was observed with hurricane Donna and persisted for a period of at least 5 hr on Sept. 6, 1960 (Jordan and Schatzle 1962). This period of 5 hr is similar to the duration of the completely closed phase of the double eye of Beulah, although the similarity may be fortuitous. Hurricane Donna had already passed through a deepening stage east of the Antilles and had weakened when crossing the Leeward Islands and while passing north of Puerto Rico. But by September 6, Donna was approaching Turks Island in the Bahamas and had begun to deepen again. The central pressure at the time of Donna's double eye, interestingly enough, was near 940 mb. At 2215 GMT on Sept. 6, 1960, a photograph of the scope of an APS-45 radar made by a U.S. Navy reconnaissance aircraft crew showed the double-eye configuration. The diameter of the inner wall cloud was about 13 n.mi., and the outer wall cloud diameter was nearly 50 n.mi. (U.S. Fleet Hurricane Forecast Facility 1960). The inner wall cloud appeared to be weakening as the reconnaissance aircraft left the storm, although it was noted on a subsequent flight a few hours later (Jordan and Schatzle 1962). This later flight, however, reported only one prominent band completely closing the eye with a 50-n.mi. diameter (U.S. Fleet Hurricane Forecast Facility 1960). This suggests that Donna's inner eye may have deteriorated in the same manner as Beulah's, leaving the outer eye band as the surviving single eye.

Another example of a double eye was reported in typhoon Sarah in March 1956 (Fortner 1958). At 2215 GMT on Mar. 24, 1956, Sarah was found to have "an eye within an eye." The diameter of the inner eye was 3 n.mi., and the outer eye had a diameter of 15 n.mi. This double eye was found at the time typhoon Sarah reached maximum intensity with a computed pressure of 937 mb.

There have been other reports of double eyes in Atlantic hurricanes in recent years; one (Staff, National Hurricane Research Laboratory 1969) was reported in hurricane Debbie on Aug. 20, 1969, but no data are available to investigate the process of its formation.

In the case of Beulah, the transition from a single eye to a double eye and back to a single eye covered a period of 13 hr. From the initial stages, beginning shortly before 1430 GMT on September 9, it took about 3 hr for the outer eye to develop a continuous wall cloud in the eastern semicircle. Two hours later at 1930 GMT, the outer eye became almost completely closed, and the resulting double-eye structure persisted for about 5 hr.

As the double eye formed, the maximum wind in the hurricane shifted gradually from the inner eye wall into the clear area between wall clouds and finally to the outer eye wall. The development of the double-eye phenomena occurred at about the time of maximum deepening of the hurricane and was accompanied by some decrease in the diameter of both outer and inner eyes and in the radius of the rain shield in the northern semicircle.

It is difficult to assess which factors have important bearing on the particular method of eye evolution observed. The reduction in the radar eye diameter and radius of maximum winds is a characteristic feature in certain types of hurricane development (Colón 1963). The one odd feature revealed by the data is that the radius of maximum winds apparently remained nearly constant, while the diameter of the radar eye decreased, with the result that the inner eye eventually became separated from, and completely encircled by, the zone of maximum winds. If this indeed occurred, then one can readily deduce that this configuration would be quite unstable, and the inner eye was probably dissipated by the subsiding downdrafts generated by the more stable developing outer eye system.

The observations reported here raise many more questions than they help in answering. They point, once more, to the interesting developments in the inner eye structure of developing hurricanes and the importance of such developments in hurricane dynamics. They also point to the need for more data-gathering efforts during the development phase of tropical cyclones.

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